MULTISENSOR PRECIPITATION ESTIMATES PRODUCED BY NATIONAL WEATHER SERVICE RIVER FORECAST CENTERS FOR HYDROLOGIC APPLICATIONS

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REFERENCE: Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, the University of Georgia, Athens, Georgia.

Abstract. The National Weather Service (NWS) produces radar-derived estimates of rainfall using data collected in real time from its network of doppler weather radars. These estimates, along with observations from automated rain gauges, are used to create high resolution gridded precipitation estimates suitable for various hydrologic applications. The NWS Southeast River Forecast Center (SERFC), located in Peachtree City, Georgia, produces these estimates for the Southeastern United States, including all of the watersheds in Georgia. The current methodology for creating these estimates, called Stage III, is being improved to address radar bias issues and to add new capabilities. The new program, called the River Forecast Center (RFC)-wide Mulitisensor Precipitation Estimator (MPE), will be installed in summer 2001. RFC-wide MPE will provide an optimal estimate of precipitation which has fallen during a given clock hour. The analysis is carried out on the Hydrologic Rainfall Analysis Project (HRAP) grid, which is a polar stereographic map projection with approximately 4 km resolution in mid-latitudes.

RADAR ESTIMATES

The Next Generation Weather Radar (NEXRAD) program has delivered over 160 new Weather Surveillance Radar-1988 Doppler (WSR-88D) radars nationally between 1991 and 1997. The WSR-88D Precipitation Processing System (PPS) computes estimates of rainfall out to a radius of 230 km from the radar by converting radar reflectivity to rain rate and integrating over time (Fulton et al. 1998). In computing the rainfall estimates, the PPS also attempts to minimize the impact of terrain-induced beam blockages by using the lowest unobstructed tilt, which, according to beam geometry and digital elevation model (DEM) data, should clear the terrain by at least 500 ft (O'Bannon, 1997).

The PPS produces graphical and gridded estimates of rainfall. While the graphical estimates have been particularly useful for the flash flood problem, it is the gridded precipitation product called the hourly Digital Precipitation Array (DPA) which is used as input into the RFC-wide MPE. The product contains an hourly estimate of the precipitation out to a radius of 230 km from the radar location. The DPA has a spatial resolution of approximately 4 km and a temporal resolution of 1 hour.

PROBLEMS WITH RAW RADAR ESTIMATES

While radar rainfall estimates provide unprecedented resolution in both space and time, there are several error sources which contribute to mean field and range dependent biases. These errors can be caused by radars which are out of calibration, the use of an inappropriate Z-R relationship when converting reflectivity to rain rate, clutter from ground targets, and bright band contamination (Smith et al. 1996).

Klazura et al. (1999) and others have shown that while the computational range of the PPS is 230 km, the true range for valid rainfall estimates is generally less than 230 km due to severe range degradation associated with beam overshoot and partial beam filling. It has also been shown that the problem with range degradation in the precipitation estimates is more severe in stratiform rainfall situations than in convective events. The observation that range effects are more severe in stratiform situations is due to the fact that stratiform precipitation tends to be more shallow than convective precipitation. This vertical structure of stratiform precipitation means that even the lowest tilt is likely to overshoot the precipitation at long range.

Smith et al. (1996) show that tendency for the radar to estimate less precipitation at long ranges from the radar can easily be observed in long term accumulations of a year or more. This range degradation problem can be observed in total accumulation, mean hourly rain rate, and in the probability of detection of rainfall as a function of range.

RADAR COVERAGE MAPS

For each radar, a map showing which grid points are well covered for precipitation estimation can be computed from long-term radar climatologies (Breidenbach et al. 2001). The coverage map also reveals which grid points cannot be reliably estimated by a specific radar due to beam blockage problems which affect that radar. The coverage map also indicates which grid points are typically beyond the range of reliable estimation. These maps vary as a function of radar location and season. In general, warm season coverage maps usually indicate good radar coverage even at long range from the radar. This is because the radar is very good at "seeing" deep cumulonimbus clouds associated with thunderstorm activity, which dominates the warm season, especially in the Southeast. However, in the cool season, much of the rainfall is produced by stratiform cloud systems, which are much shallower than convective activity and therefore easily overshot by the radar beam. Radar coverage maps derived from cool season data generally reflect this situation and indicate no or poor coverage for grid points at long ranges from the radar. Accurate radar coverage maps from both the warm season and the cool season are needed to create accurate multi-radar precipitation mosaics.

MULTI-RADAR MOSAICS

The first step in creating a multisensor estimate of precipitation is to create a multi-radar mosaic. The Multi-radar mosaic is computed by mapping data from each radar onto a larger grid which covers an entire RFC area of forecast responsibility. In areas where more than one radar covers a particular grid box, the radar which provides data at the lowest height above sea level is used in the mosaic. It is also important to note that when the radar coverage map for a given radar shows that a grid point is not well covered by that radar, an attempt is made to fill in the grid point with data from another radar. This methodology is much better than using either the maximum or the mean value from multiple radars in areas covered by more than one radar. Either of these alternate methods is likely to result in an underestimation in areas covered by more than one radar, since these are also areas that are usually a long distance from all radars.

The mosaic methodology of using individual radar coverage maps and then selecting the lowest available coverage may leave some grid points which are not well covered by any radar. Even though some grid points may not be defined in the radar coverage, it is better to know where the radar network provides poor coverage and use other types of data such as rain gauge or satellite to help fill in these gaps. The multi-sensor algorithm discussed below fills in these missing grid points using information interpolated from near by gauge observations and nearby grid points which are well covered by at least one radar.

A map showing the multi-radar coverage for the SERFC area of forecast responsibility is shown in figure 1. The map shows which radar provides the best coverage for each grid box and that data from twelve separate radars are used to provide optimal coverage for the entire state of Georgia.

BIAS CORRECTION OF RADAR ESTIMATES

A mean field bias correction factor is computed for each radar and updated each hour based on collecting co-located gauge radar pairs (Seo et al.,1999). The bias correction factor is based on a recursive estimation and exponential smoothing technique which essentially divides the sum of the gauges by the sum of the radar observations collected in time and space. Valid gauge-radar pairs are collected only from areas where the radar provides good coverage as determined by the radar coverage map. In order to collect enough pairs for a stable and statistically significant bias computation, observations are collected, and bias corrections computed, for multiple time periods . Once a reliable bias correction factor is computed, it is applied to the radar mosaic by multiplying it times every grid point covered by the radar for which it was computed. Similarly, bias correction factors are computed for each radar and applied to appropriate locations in the mosaic.

The mean field bias correction can account for bias in the radar estimates due to poor radar calibration and inappropriate Z-R relationships. However, nonuniform biases, which can vary from grid point to grid point due to radar sampling issues as well as differences in airmass or rainfall type (convective vs. stratiform), are not handled well by a mean field bias correction.

MULTI-SENSOR ESTIMATES

Rain gauge observations are merged with the estimates from the bias-corrected radar mosaic using an optimal estimation procedure (Seo, 1998). In the optimal estimation procedure, the value of each grid point is determined by weighting gauge and radar observations in the vicinity of the grid point which is being estimated. By definition, the weights for the gauge and radar are determined such

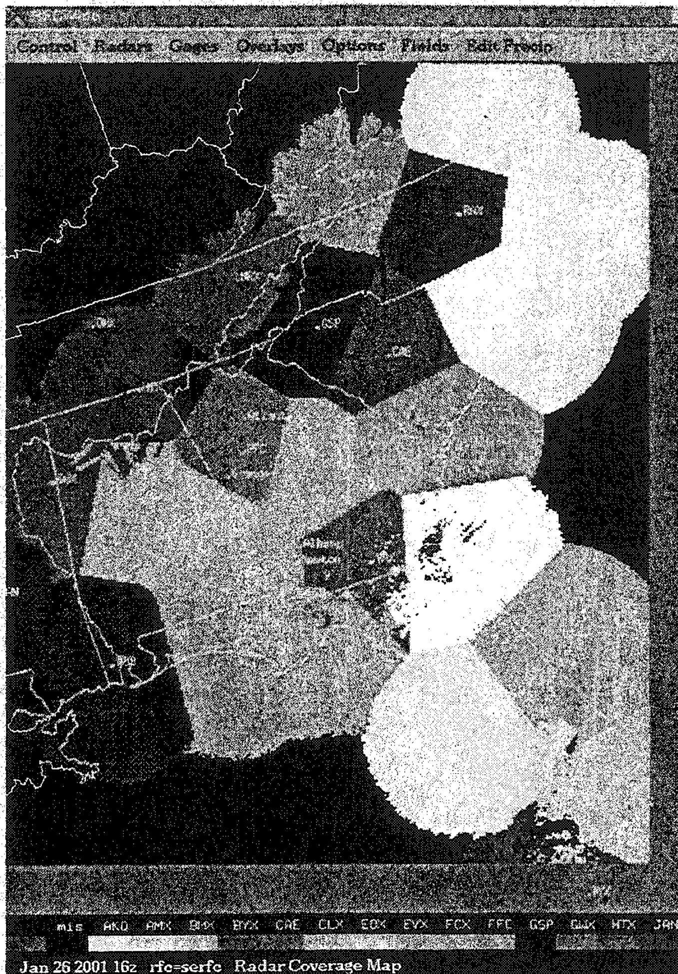

Figure 1. Multi-radar coverage map based on choosing the lowest available coverage for the SERFC area of forecast responsibility. Individual radar coverage maps determined from climatological analysis of frequency of rainfall.

that their linear combination minimizes the expected error variance of the analysis. Since a gauge observation is considered to be "truth," the optimal estimate matches the gauge value at the gauge location and places a heavy weight on the gauge value in the vicinity of the gauge location. The amount of weight placed on the radar estimate at a given grid point increases as a function of distance from the nearest gauge.

MULTISENSOR PERFORMANCE

RFC-wide MPE is being tested at the Middle Atlantic River Forecast Center and the West Gulf River Forecast Center. Verification of each of the fields (raw radar mosaic, bias-corrected mosaic, and multisensor mosaic) has been performed on several cases. The results consistently indicate that the multisensor field has the least bias, smallest RMS error, and highest correlations with respect to independent gauge samples. For example, verification of the precipitation fields observed during hurricane Floyd at Mid-Atlantic RFC show that the correlation coefficient of 0.77 for the raw radar estimate was improved to 0.91 for the multisensor estimate.

HYDROLOGIC APPLICATIONS

The RFC-wide multisensor precipitation estimate can be used as input into the National Weather Service River Forecast System (NWSRFS). Currently, precipitation input into NWSRFS is handled in a "lumped" fashion, where basin average rainfall is tallied up for 6-hour periods and then input into a calibrated Sacramento soil moisture accounting model for that basin.

The NWS Hydrology Laboratory is conducting research to study the use of this type of high resolution data in distributed hydrologic models which operate at a much higher resolution in time and space. Other agencies and research groups need this type of data for distributed modeling purposes as well.

Calibration of distributed hydrologic models remains an important issue. We are now beginning to approach a long enough time series of radar data, (1996-2000), so that effective development and calibration of distributed hydrologic models can be performed. To create an accurate multisensor gridded data set for the period of record, radar and gauge data will need to be re-analyzed using the new algorithms discussed in this paper.

Such a project is now underway for the area covered by the SERFC. The re-analysis project is being led by Florida State University in collaboration with the NWS, with partial funding from the Florida Department of Environmental Protection.

One of the most difficult things associated with both real-time estimation and a re-analysis is finding enough high-quality hourly gauge observations for the bias correction and multisensor algorithm. In many cases, high-quality hourly gauge data has been collected by local water management authorities in real time and archived. However, in some cases this gauge data has not found its way to the NWS, where it could be used to further improve the multisensor analysis.

SUMMARY AND CONCLUSIONS

Multisensor precipitation estimation, which uses both radar and rain gauge information, produces the most accurate and highest resolution gridded estimates of rainfall. These estimates are suitable for real time hydrologic forecasting. A re-analysis of all radar and gauge data, including gauge data archived by local water management authorities, will produce a high resolution data set for the period of record which is suitable for distributed hydrologic model development and hydrologic model calibration.

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